Ecosystem Services and Climate Change

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Introduction

Ecosystem services play an important role in strategies for tackling climate change: mitigation and adaptation (Turner et al., 2009). Mitigation aims at reducing emissions sources or enhancing sinks of greenhouse gases, and adaptation aims at adjusting natural or human systems to moderate harm or exploit beneficial opportunities from climate variations (Figure 38. 1). Because of their different rationales, these strategies have different priority sectors and locations: mitigation prioritizes larger emission sources or stronger potential sinks, whereas adaptation prioritizes vulnerable people, ecosystems and activities. While some sectors are mostly concerned by one of the two strategies (e. g., energy by mitigation or health by adaptation), ecosystems and their services are clearly relevant to both.

Ecosystems contribute to mitigation because of their capacity to remove carbon from the atmosphere and to store it. Ecosystems contribute also to adaptation because they provide services that can help people adapt to both current climate hazards and future climate change (Figure 38. 2). While ecosystem services are part of the solution to climate change, they are also affected by changing climatic conditions. Ecosystem-based approaches to climate change should recognize the multiple links between ecosystem services and climate change: management can enhance the contribution of ecosystem services to adaptation and mitigation ('ecosystem-based adaptation and mitigation') and, as climate change will affect ecosystems and their services, adaptation measures are needed to reduce negative impacts and maintain ecosystem functions ('adaptation for ecosystem services').

This chapter explores the links between ecosystem services and climate change. It first describes the ecosystem services that contribute to mitigation and adaptation, as well as the threat of climate change to ecosystem services. Here the focus is on provisioning services (e. g., food and timber) and regulating services (e. g., water regulation and pest control), as there is little evidence on how adaptation benefits from cultural services (e. g., recreation, aesthetic and spiritual benefits). In the section on adaptation services, only services that contribute directly to human well-being and resilience are considered, and so supporting services (e. g., primary production and nutrient cycling) are excluded. However, because they are important for ecological resilience, they will be considered in the section on climatic threats. The chapter will end with an overview of policy instruments related to ecosystem-based adaptation and mitigation, and the trade-offs that arise when pursuing the strategies jointly.

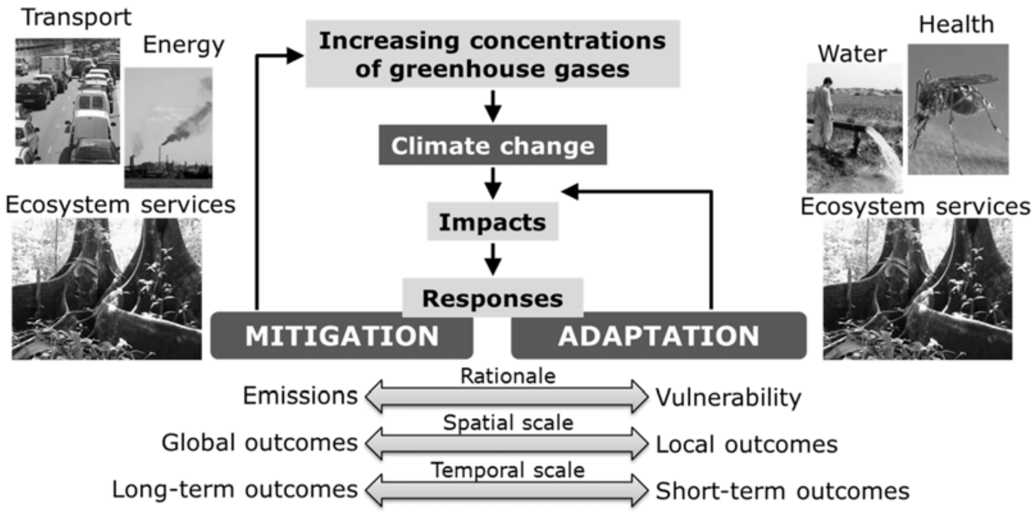

Figure 38.1 Differences between climate change adaptation and mitigation

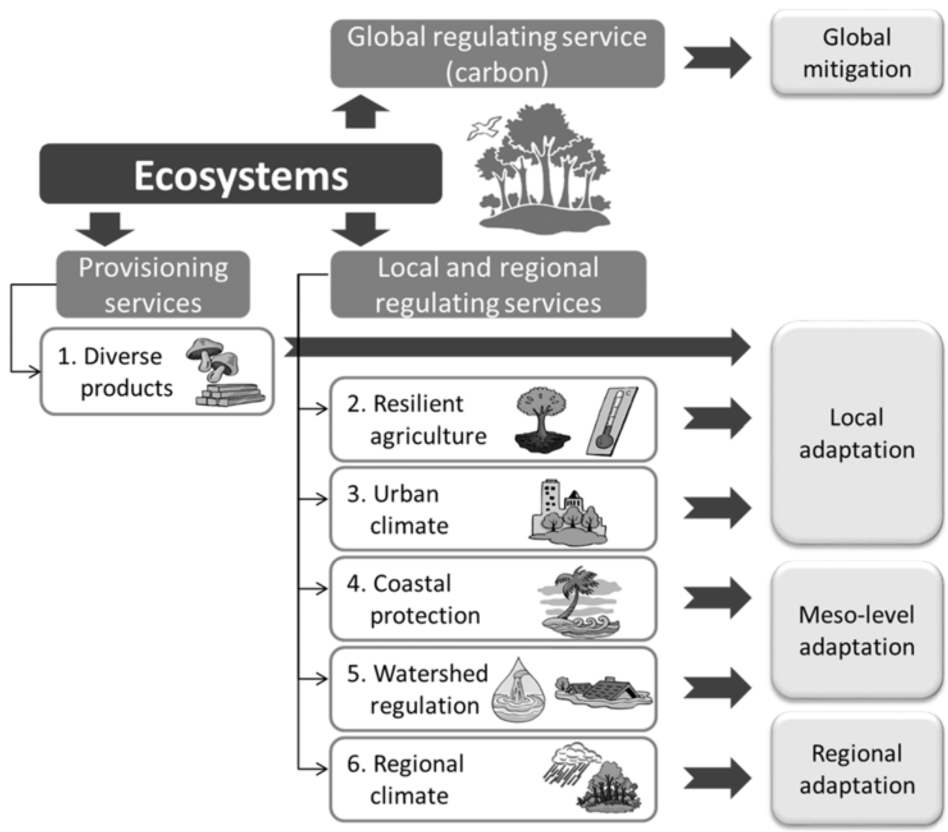

Figure 38.2 Contribution of ecosystem services to climate change adaptation and mitigation

Mitigation services

Ecosystems contribute to mitigation because of their capacity to remove carbon from the atmosphere and to store it. Terrestrial ecosystems absorb around 3 billion tons of atmospheric carbon per year (Pg/yr) through net growth, which accounts for 30% of anthropogenic CO_2 emissions (Canadell and Raupach, 2008). Forest ecosystems play a crucial role in carbon sequestration, particularly tropical forests, but tropical deforestation causes carbon emissions, estimated between 0. 8 to 2. 8 Pg/yr (Baccini et al., 2012; Harris et al., 2012), equivalent to 6–17% of global anthropogenic CO_2 emissions to the atmosphere (Van der Werf et al., 2009).

Thus, ecosystem management can contribute to climate change mitigation. Afforestation (converting long-time non-forested land to forest) and reforestation (converting recently non-forested land to forest), for example, increase carbon in the vegetation, whereas forest conservation contributes to reducing carbon emissions from deforestation. Agricultural management can also enhance carbon sequestration through soil conservation and the introduction of trees in agroforestry systems (Uprety et al., 2012).

Adaptation services

Well-managed ecosystems can help societies to adapt to current climate hazards and future climate change by providing a range of ecosystem services (Doswald et al., 2014; Pramova et al., 2012b). Six key areas are reviewed here.

Products and local communities

Provisioning services play an important role in the coping and adapting strategies of rural communities, particularly in developing countries (Innes and Hickey, 2006). Many rural communities use forest products as safety nets for coping with stresses, as when agriculture production fails due to drought. During floods in Peru (Takasaki et al., 2004) and droughts in Tanzania (Enfors and Gordon, 2008), coping strategies include collecting forest wild products. After a hurricane in Honduras, the collection and trade of forest products helped households recover (McSweeney, 2005).

Timber and non-timber forest products (such as firewood, wild fruits, mushrooms and fodder) also contribute to livelihood diversification, an adapting and anticipatory strategy that reduces the sensitivity of households and communities to climate variations. Numerous studies have demonstrated the importance of ecosystem provisioning services for livelihood diversification and resilience in Bolivia (Robledo et al., 2004) or in Cameroon (Bele et al., 2011), for example. In Morogoro (Tanzania), the main strategy of rural communities for dealing with climate variability is livelihood diversification, partly through firewood or fruits (Paavola, 2008). Complex cropping systems, with associated multiple species of crops, fodder and trees, provide a continuous harvest of products despite climate variations in Mali (Djoudi et al., 2013) and Bangladesh (Rahman et al., 2012), for example.

The coping and adapting strategies of the poorest or most vulnerable households often rely heavily on ecosystem products, because of the lack of alternatives and the limited requirements in financial, physical or human assets for collecting these products. This reliance has been observed among young and poor households with limited land access during a flood in Peru (Takasaki et al., 2004), households with low income or headed by older and less-educated individuals during droughts in

Malawi (Fisher et al., 2010) and the poorest and least-educated people after a flood in Indonesia (Liswanti et al., 2011). As a result, farmers and pastoralists with limited access to forest products are more vulnerable to rainfall variations than others in Kenya (Owuor et al., 2005) and the lack of access of mangrove resources increases the vulnerability of poor coastal communities in the Philippines (Walton etal., 2006). As the use of provisioning services for coping with stresses often results from a lack of alternative strategies, it can be a symptom of poverty rather than a solution for adaptation (Pattanayak and Sills, 2001). Ecosystem services as a safety net can be a poverty trap, particularly when resource availability is low, the population in need is large and alternatives are lacking (Levang et al., 2005).

Local climate regulation in agriculture

As trees in or near agricultural fields provide regulating services that reduce the vulnerability of cropping systems to climate variations, the introduction of trees in agriculture, such as in agroforestry and silvopastoralist systems, is considered as an effective adaptation strategy. Tree roots explore soil deeply for water and nutrients, which benefits crops during droughts. Trees improve fertility and protect soils from erosion by increasing soil organic matter, porosity, infiltration and soil cover (Verchot et al., 2007). Nitrogen-fixing trees contribute to the resilience of crops to droughts due to improvements in soil nutrients and water infiltration, as research has shown, for example, in Malawi and Zambia (Garrity et al., 2010). In Niger, cereal production was less affected by recent droughts in areas with tree regeneration (Sendzimir et al., 2011). As shade trees control temperature and humidity and protect from winds and storms, they can also improve the resilience of coffee and cacao production in, for example, Mexico (Lin, 2010).

Studies on agroforestry systems highlight trade-offs. For example, high tree cover increases soil protection but reduces the light available to crops in the understorey, which requires the identification of the context-specific tree cover that maximizes the benefits of agroforestry. Other trade-offs occur between average yields and resilience: tree cover buffers crops against climate stress but decreases average yields in the absence of stress. In agroforestry, tree ecosystem services may contribute differently to crop adaptation to climate change depending on climate scenarios and production systems (Verchot et al., 2007).

Despite the benefits of agroforestry, its expansion has been constrained by policies promoting intensive agriculture systems that exclude trees or, in some cases, induce deforestation (Morton et al., 2008). Other approaches are possible, in which agricultural intensification occurs in association with trees, so that ecosystem services and incomes are secured (Steffan-Dewenter et al., 2007). The social and biophysical context determines how land-use and agricultural policies balance land sparing (maximization of agricultural production in some areas and conservation of natural ecosystems in others) and land sharing (integration of conservation and production in heterogeneous landscapes) (Fischer et al., 2008).

Local climate regulation in cities

As urban forests and trees regulate temperatures (through shade and evaporative cooling) and water (through rain interception and infiltration), they play a role in urban adaptation to climate variability and change. Because of their impermeable surfaces, cities are vulnerable to flooding, but urban parks or trees can reduce runoff through infiltration. The urban heat island effects, which increase the health impacts of heat waves, are moderated by green cover, as observed, for example, in Manchester, UK (Gill et al., 2007).

In cities, ecosystem-based adaptation requires a good understanding of landscape ecology and the potential of green infrastructure to improve the well-being of vulnerable communities, as in the case of Durban, South Africa (Roberts et al., 2012). Adaptation needs also to be designed at multiple scales, including ecosystem management outside the urban areas and for upper watershed protection. For example, three scales are proposed in Beijing, China, for a green infrastructure at the regional scale (forest belts), in the city (urban parks and green corridors) and in neighbourhoods (road and vertical greening) (Li et al., 2005). However, urban ecosystem- based adaptation raises concerns about high opportunity costs of land and possible management constraints: for example, during droughts, scarce water consumed to maintain trees may be needed for other uses.

Protection of coastal areas

By stabilizing land and absorbing and dissipating wave energy, coastal ecosystems such as mangroves can protect coastal areas from climate-related threats: tropical storms, sea-level rise, floods and erosion. The protection services of mangroves against storms were evident after a cyclone in Orissa, India (Das and Vincent, 2009) and are recognized by coastal communities in Bangladesh (Iftekhar and Takama, 2008). Coastal forest management has been suggested to control beach erosion from future sea level rise in Zanzibar, Tanzania (Mustelin et al., 2010), for example. In Vietnam, planting mangroves reduce the costs of maintaining sea dykes built for protecting coastal settlements (Adger, 1999).

It is unclear how much mangrove is needed to reduce the vulnerability of a coastal area to different threats and how the protective role is influenced by topography, bathymetry or mangrove extent and species. Mangrove width is an important factor, but the minimal width for a given area also depends on mangrove structure and species. Plans should be based on a good understanding of coastal dynamics and mangrove role (Feagin et al., 2010). In addition, as coastal ecosystems cannot guarantee complete protection from extreme events, they should be part of a broader disaster risk reduction and adaptation strategy (Baird et al., 2009).

Protection of watersheds

Ecosystems influence the hydrological functioning of watersheds through their contribution to rainfall interception, evapotranspiration, water infiltration, and groundwater recharge. This influence can reduce the impacts of climate variations on downstream population. For example, ecosystems can preserve base flows during dry seasons if they facilitate groundwater recharge; they can also reduce peak flows or floods during rainfall events if they contribute to rainfall interception and infiltration. In addition, ecosystems can reduce soil erosion and landslide hazards, which are partially climate-related. Higher base flow in forested watersheds reduced the impacts of droughts on downstream farming communities in Flores, Indonesia (Pattanayak and Kramer, 2001). Natural forest regeneration improved water provision to agriculture during extended dry periods, stabilized hillsides and reduced the impacts to soil erosion and landslides on communities in Bolivia (Robledo et al., 2004).

Even though hydrological studies on forests and water could inform decisions on adaptation, few deal with extreme events and social vulnerability to water and soil-related hazards. In addition, the influence of forests on floods is debated. Even if forests can reduce storm flow because of their higher infiltration, this effect is questioned in the case of large rainfall events once soils are saturated with water (Bruijnzeel, 2004). However, in spite of such controversies, the role of forests in the most frequent medium-scale floods should not be overlooked (Locatelli and Vignola, 2009). Similarly, controversies exist on the effect of forests on base flow, because it results from two competing ecosystem processes: in forests, high transpiration reduces base flow whereas high infiltration increases soil water recharge and base flow. Regarding soil erosion and landslides, hydrological literature confirms that surface erosion is generally low in forests; however, uncertainties remain about the role of forests in landslide prevention, especially when high rainfall intensity overwhelms the role of roots in stabilizing soils (Sidle et al., 2006).

Climate regulation at regional and continental scale

At the regional and continental scale, ecosystems play a role in recycling rainfall and generating flows of atmospheric water vapour. While evapotranspiration by forests reduces total water flows in a watershed, it also pumps water back into the atmosphere, which can increase rainfall in the region (Ellison et al., 2012). Forests may also act as a pump of atmospheric moisture, attracting moist air from oceans to inland regions (Makarieva and Gorshkov, 2007; Sheil and Murdiyarso, 2009), but this role of forests in hydrological processes at the regional scale is debated (Meesters et al., 2009). The role of forests and trees in regulating atmospheric water and regional rainfall has been overlooked by scientific assessments on ecosystems and climate change, despite its place, for example, in moderating droughts effects due to global climate change.

Climate threats on ecosystem services

Most ecosystems are vulnerable to climate change even under low- and medium-range scenarios of global warming (Scholes and Settele, 2014). They are likely to be affected by gradual changes in temperature or precipitation and climate-related disturbances (e. g., flooding, drought and wildfire), in association with other threats (e. g., land use change, pollution, overexploitation of resources). These changes and disturbances will affect ecosystem structure and function, the ecological interactions among species and their geographical ranges, which will result in changes in biodiversity and ecosystem services (Locatelli et al., 2008). Ecosystem vulnerability has consequences for the global climate: if changes and disturbances release carbon into the atmosphere, vegetation-climate feedback will amplify global warming (Canadell et al., 2004). Local and regional ecosystem services may also be affected by climate change, such as water regulation or timber production, with direct implications for dependent societies (Shaw et al., 2011).

The resilience of ecosystems in a context of climate change depends on multiple factors, such as other non-climatic pressures, landscape configuration and species richness and diversity (Locatelli et al., 2008). Nutrient cycling and primary production are important components of the functioning, resistance and resilience of the ecosystem and we need to understand more the ecological mechanisms that facilitate the maintenance and adaptation of ecosystem services during periods of change (Lavorel et al., 2015).

Where short-term or non-climatic threats to ecosystems are minimized, specific measures for climate change adaptation can be incorporated into management. Management can reduce the risks linked to climate change and increase the capacity of ecosystems and species to adapt (Scholes and Settele, 2014). Actions can buffer ecosystems from perturbations, such as through fire or pest management, or facilitate ecological adjustments to changing climates, such as by reducing landscape fragmentation to facilitate species migration (Guariguata et al., 2008). Adaptation must, however, be an on-going process rather than seeking to maintain existing conditions or targeting a new equilibrium (Stein et al., 2013).

Existing policy instruments

Ecosystem-based mitigation of climate change is now recognized by international agreements and policy instruments. For example, the contribution of tropical afforestation and reforestation is acknowledged in the Clean Development Mechanism (CDM) of the Kyoto Protocol, and several plantation projects are rewarded through this mechanism or voluntary carbon agreements. Another initiative is REDD+ (Reducing Emissions from Deforestation and forest Degradation (Angelsen et al., 2012)). This aims to maintain carbon stocks based on the provision of financial incentives to protect forests from deforestation and degradation, and enhance carbon stocks through sustainable forest management.

The place of ecosystem-based approaches in the international discussions is not as clear for adaptation as it is for mitigation, but some initiatives have been developed at national and local scales (Locatelli et al., 2011). Among the 44 National Adaptation Programmes of Action (NAPAs) submitted by least developed countries to the UN Framework Convention on Climate Change (UNFCCC) by mid-2010, more than half recognized the importance of ecosystem services (Pramova et al., 2012a). Around 25% of the adaptation projects in the NAPAs included ecosystem management activities for improving human well-being and adaptation through such measures as soil rehabilitation, erosion control and water regulation.

Ecosystem-based approaches to climate change: the way forward

Many projects and programs are contributing to effective mitigation and adaptation strategies through the conservation of biodiversity and ecosystem services (World Bank, 2009), though they rarely consider both adaptation and mitigation (Locatelli et al., 2015). A comprehensive approach must encompasses three dimensions: ecosystem-based mitigation, ecosystem-based adaptation, and adaptation for ecosystems (Figure 38. 3). To ensure that ecosystems mitigate climate change and help people adapt, management must reduce current threats to ecosystem services (e. g., deforestation and forest degradation) as a first step. It should also address future threats by developing adaptation measures. In ecosystem-based approaches to climate change, 'adaptation for ecosystems' is thus needed to ensure that ecosystem-based adaptation and mitigation work in the long term.

The management of ecosystem services can provide joint benefits for both mitigation and adaptation where, for example, the spatial distributions of carbon, hydrological services or biodiversity are positively correlated (Locatelli et al., 2014). For example, mangrove conservation and restoration simultaneously contribute to protecting coastal areas and to storing large amounts of carbon (Donato et al., 2011). Forest conservation projects for mitigation, such as REDD+ projects, can improve the adaptation of local livelihoods by increasing the provision of local regulation ecosystem services to communities, protecting them from hydrological variations. They can also contribute to diversifying incomes and economic activities through the use of provisioning services such as non-timber forest products. REDD+ projects can also facilitate ecological adaptation to climate change by reducing anthropogenic pressures on forests, enhancing connectivity between forest areas and conserving biodiversity hotspots (Locatelli et al., 2015).

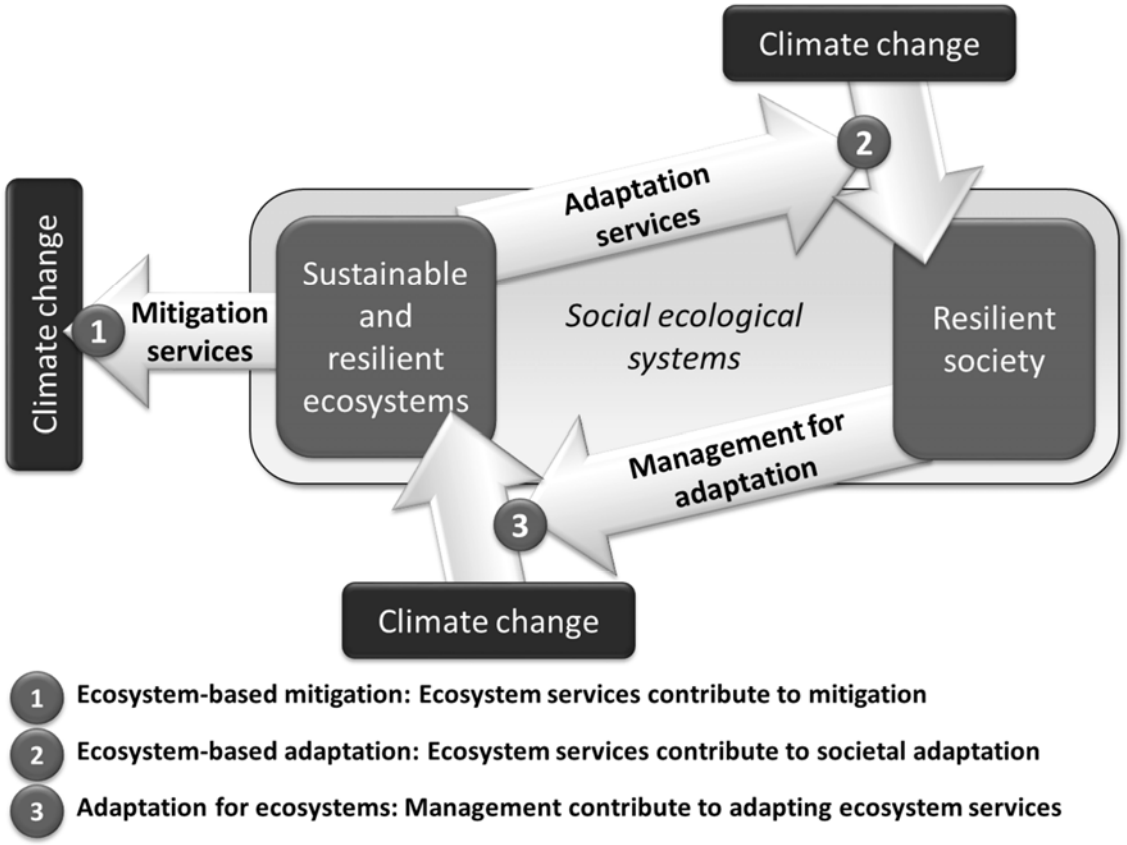

Figure 38. 3 The three pillars of ecosystem-based approaches to climate change

But trade-offs between adaptation and mitigation can occur. Adaptation can lead to increased emissions: for example, if ecosystem management aims at improving water balance for adapting water users to climate change, the best outcomes may in some cases be achieved through ecosystems with low carbon content, such as grasslands, rather than forests (Locatelli and Vignola, 2009). Conversely, mitigation can increase vulnerability. For example, a monoculture using species with fast growth and high water consumption can perform well in terms of carbon storage and mitigation, but cause downstream water shortages and biodiversity losses, which can then increase social and ecological vulnerability to climate change. The IPCC have warned that the widespread transformation of ecosystems for mitigation, such as planting fast-growing tree species or bioenergy plantations, will negatively impact ecosystems and biodiversity (Scholes and Settele, 2014). A REDD+ project may increase livelihood's vulnerability if it restricts the rights and access of local people to forest provisioning services.

Although adaptation and mitigation present notable differences, particularly in their objectives, spatial and temporal scales, there is an increasing need to pursue them jointly (Warren, 2011). Given that ecosystems can provide mitigation and adaptation services at the same time, policies and local initiatives related to ecosystem management can integrate both climate change strategies and avoid trade-offs between them. Beyond the adaptation-mitigation integration, there is a need to mainstream climate change in the policy domains of ecosystem management and rural development (Kok and de Coninck, 2007).

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